DISCUSSION ABOUT METAL EXPANSION JOINTS MANUFACTURING TECHNOLOGY OF PREVENTING THERMAL DEFORMATION PIPELINES INTENDED FOR THE FLUIDS TRANSPORT

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Resume

In this paper, the authors discuss the method of deformations compensation (resulting from the impact of variable temperatures and pressure) in pipelines intended for fluids transport (liquids and gases). Classical methods of compensation through the so-called "natural compensation" and using special devices called expansion joints. In this paper authors present research work on a new type of the metal expansion joints, called bellow-lens expansion joints. The mechanically assisted laser forming method, which was used to manufacture the bellow-lens expansion joints, was presented. The method uses CO_2 laser radiation to heat the element from which the expansion joint will be made and the proprietary system consists of an actuator and swivel handle.

Available online: https://doi.org/10.26552/com.C.2023.030

Article info

Received 7 November 2022
Accepted 3 February 2023
Online 23 February 2023

Keywords:

metal expansion joints
laser forming
pipelines compensating
pipelines thermal deformation

ISSN 1335-4205 (print version)
ISSN 2585-7878 (online version)

1 Introduction

Industrial transport systems, commonly called pipelines, are used to move mainly fluids such as, for example: natural gas (gas pipelines), oil (oil pipelines), steam and water (power pipelines) and others. These types of installations operate with various operating parameters, such as temperature and pressure [1]. Inadequate construction of such a pipeline may lead to its damage and, consequently, even to a huge catastrophe and threat to human health and life and the natural environment.

Therefore, the pipeline spools should be designed in such a way that the deformations arising from changing temperatures and changing pressures will be compensated. One of the easiest ways to compensate for this type of deformations are “natural” spool direction changes, implemented on standard fittings, such as elbows or tees. If the route of the pipeline does not assume a change of direction, then the special “loops” should be designed to enable this type of compensation. The method of compensation for “natural” direction changes and “loop” is presented in Figure 1.

This type of solution is applied where there is a lot of space to use a “loop”, mainly on overhead and underground pipelines. However, it is not always possible, e.g. due to lack of space or technological and economic limitations. In such circumstances, specialized devices, called lens compensators or bellows compensators, are used [2]. As the name suggests, on the circumference of the pipe there are bellows or, less often, lenses that can expand and contract under the influence of temperature (similar to the bellows in an instrument called an accordion), thus acting as a compensator (expansion joint). The classic methods of producing these elements are plastic working on sets of rollers, hydroforming, redrawing and welding.

The authors of this paper proposed to produce a new type of metal expansion joint called a bellow-lens expansion joint (combining the advantages of two

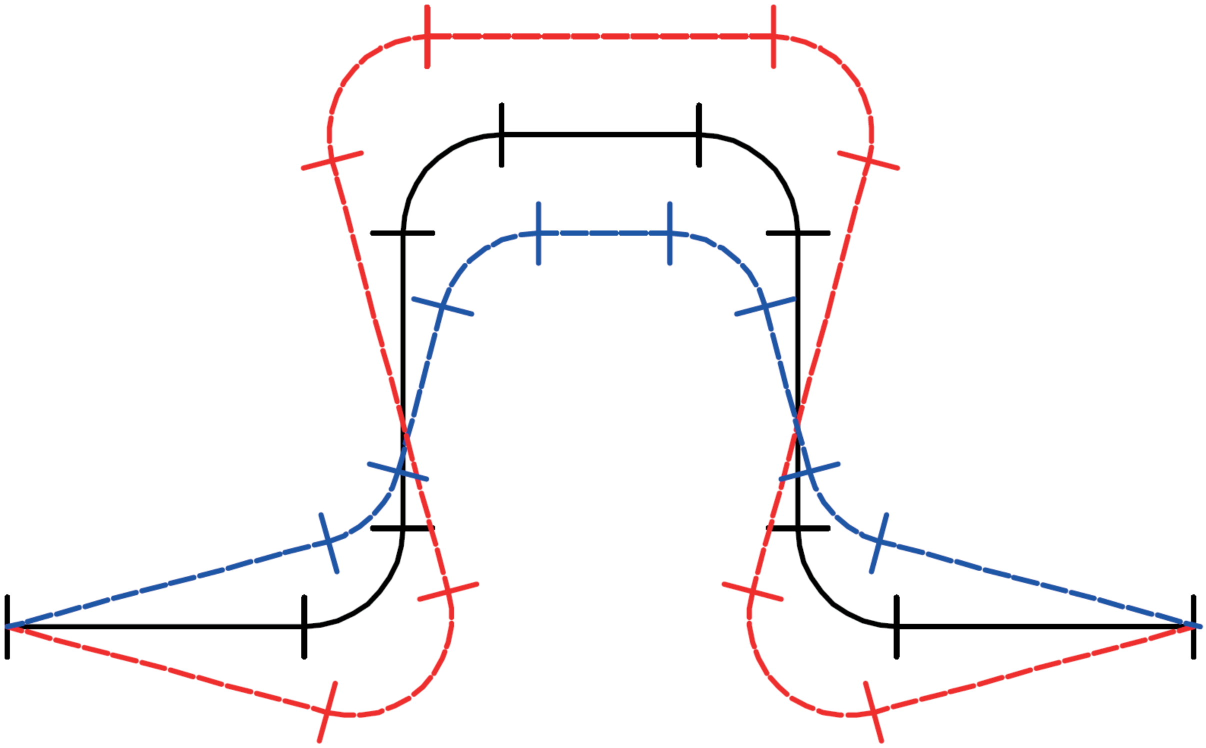


Figure 1 *Pipeline thermal compensation on elbows, the so-called "natural" in the form of a "loop". Schematically showed: black line - nominal pipeline route (designed route), red line - compensation caused by material expansion (temperature rise), blue line - compensation caused by material shrinkage (temperature drop)*

types: a bellow joint with a lens expansion joint) by using laser treatment. Currently, laser technologies are very widespread in industrial practice. They are used to perform such industrial operations as: cutting, welding, industrial coatings applications, creating textures on the material's surface, additive manufacturing etc., [3-8].

In addition to the above-mentioned laser technologies, we also have a laser forming technique. The phenomenon of material deformation as a result of the element's local temperature change is used here. The element is locally heated by the energy of the laser beam acting on it. The appropriate geometry and trajectory of the laser beam led to the desired shape of the element. In this case, the local shape change of the element is achieved due to the difference in thermal expansion of the "cold" and "warm" parts of the material. Plastic deformation is achieved by causing internal thermal stresses in the material without the participation of external forces. Vollertsen [9] distinguished three main mechanisms of laser forming: the temperature gradient mechanism (TGM), the upsetting mechanism (UM) and the buckling mechanism (BM).

The mechanisms presented above apply to laser forming, without the participation of external forces. The disadvantage of this type of technology is its time and energy consumption. According to this fact, to speed up the laser forming process, it was decided to additionally use external forces. Technologies that use a laser beam as a heat source are called laser-assisted forming or mechanically assisted laser forming [10-13].

The concept of the mechanically assisted laser forming method, which technology was used to manufacture expansion joints, are presented below. The results of experimental research are presented, as well.

2 Method concept

The concepts of new metal expansion joints manufacturing process, using a mechanically assisted laser forming hybrid method, are described in paper [13] and the patent [14]. Below is a general description of the metal expansion joints manufacturing concept to introduce the assumptions of the technology to the readers. Figure 2 presents a conceptual stand for expansion joints manufacturing. The description of the method is given below.

The general conception of bellows-lens expansion joints manufacturing is as follows (see Figure 2):

1. The starting element is a pipe (1) with a known diameter and wall thickness, made of a material of an appropriate grade.
2. The pipe (1) is placed between the actuator (5) and the swivel handle (6).
3. The pipe (1) is set into rotation ω.
4. The laser head (2) guiding the laser beam with the power P heats the pipe (1) in the given area to the plasticization temperature T.
5. The plasticization temperature T is monitored in real-time by a pyrometer (3) coupled to the laser

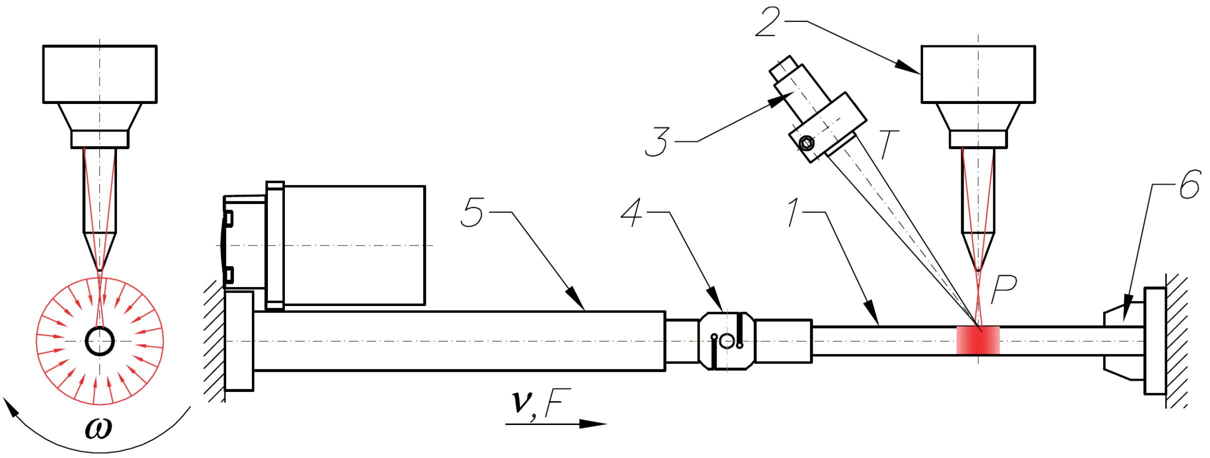


***Figure 2** The execution and measurement stand concept: 1 - pipe quickly rotating around its axis, 2 - laser head (pipe heating), 3 - pyrometer, 4 - force sensor, 5 - axial thrust actuator, 6 - swivel handle*

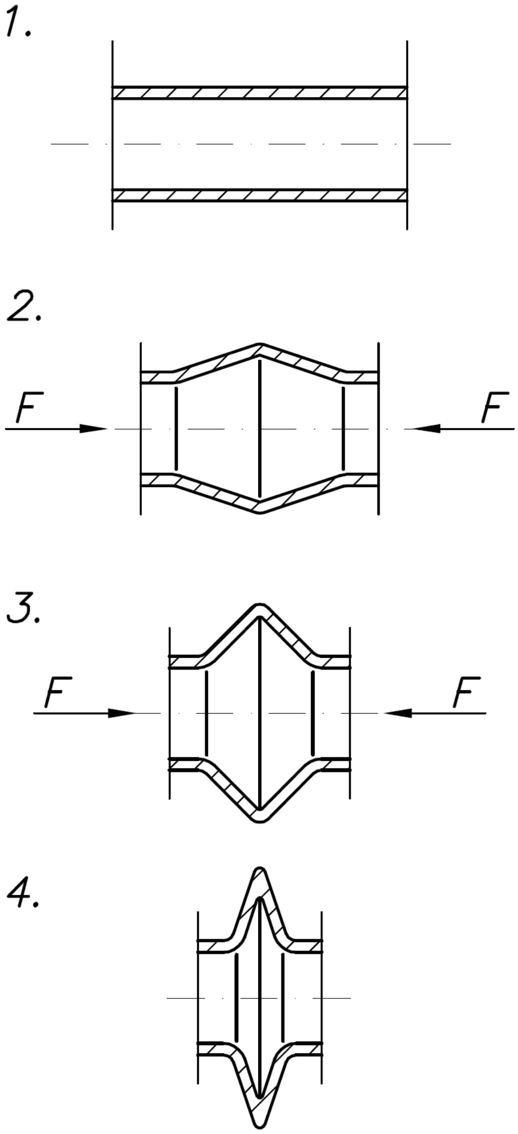


***Figure 3** Individual steps of bellow-lens forming (concept):*
1 - straight output pipe, 2, 3 - pipe upsetting, 4 - the final bellow-lens shape

Table 1 *Chemical composition, main physical properties and mechanical properties of X5CrNi18-10 austenitic stainless steel*

Chemical composition (wt. %)							
C	Cr	Ni	Mn	Si	P	S	N
<0.07	17.5 ÷ 19.5	8.0 ÷ 10.5	<2.0	<1.0	<0.045	<0.015	<0.11

Density ρ (kg/m^3)	Thermal expansion coefficient α (1/K)	Heat capacity C_{p20} (J/kgK)	Thermal conductivity λ (W/mK)
8020	14.2x10^{-6}	480	15
Proof stress $R_{0,2}$ (MPa)	Tensile strength R_m (MPa)	Elongation at fracture A_{80} (%)	Hardness (HV)
230	540-750	35-45	min. 220

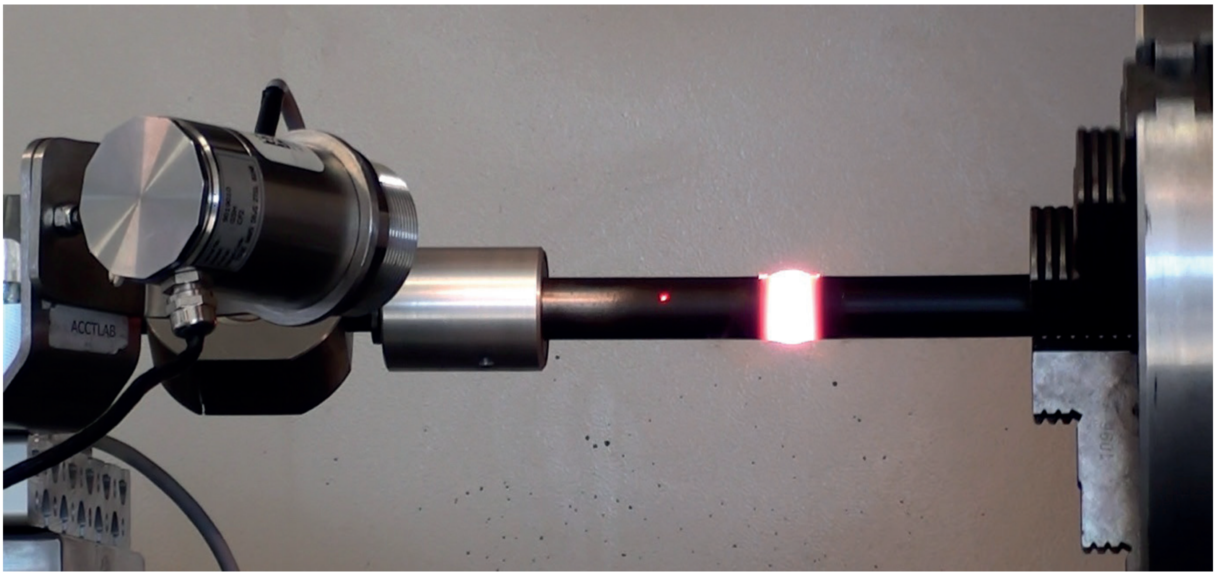


Figure 4 *Pipe in the course of the experiment: heating and compression process*

device. This allows the plasticization temperature to be kept constant.

6. After reaching the appropriate plasticization temperature T, the actuator (5) presses onto the pipe (1) with the force F and the velocity ν.
7. The pushing force is recorded by a force sensor (4) installed between the actuator (5) and the pipe (1). The final result is the formation of a bulge, which is a bellows-lens expansion joint. The individual stages of bellows-lens formation are presented in Figure 3.

The concept presented above was verified by experiment. The results of the experiment are presented in the following section.

3 Materials, methods and experimental results

A stainless steel pipes, of dimensions of ϕ20 x 1 mm (DN20) and ϕ50 x 1.5 mm (DN50), were used for the experiment. The elements are made of austenitic steel X5CrNi18-10 grade. The surface of the specimens was covered with a special absorber to increase the laser radiation absorption. The specimens were mounted in the previously described device. The actual view of the test stand is shown in Figure 4. The chemical composition and selected physical properties of this steel are presented in Table 1 [15].

A TRUMPF TruFlow 6000 CO_2 laser with a maximum power of 6kW was used for the experiment. The laser treatment parameters were as follows:

- laser wavelength: λ =10.6 μm,
- CW laser mode,
- laser power (recorded): P = 900-1100 W (for DN20 pipe); P= 1000-1300 W (for DN50 pipe),
- process temperature: approx. T = 1050-1100 °C (directly heated zone),
- compressive length: s = 10 mm (for DN20 pipe); s = 25 mm (for DN50 pipe)
- pipe rotation speed: ω = 10 000 °/min,
- pipe compressive speed: v= 10 mm/s.

The process of mechanically assisted laser forming uses proprietary research equipment, made by the authors especially for this purpose. The device consists of an execution stand and a control cabinet. The execution stand is attached to the frame of the CNC chuck cooperating with the TRUMPF TruFlow 6000 CO_2 laser. It is equipped with a linear actuator with a stepper motor and a strain gauge force sensor (Figure 2). The Siemens S7-1200 PLC controller was installed in the control cabinet. Its task is to read signals from sensors, generate control signals, manage the process and communicate with the operator's dedicated application on a PC (the application was developed by the authors of this paper).

The way the equipment works is as follows. Based on the parameters set by the operator and readings from the sensors, control signals are generated. The working process starts automatically when the set sample temperature is reached. The actuator moves to the set position with the control of the maximum force compressing the specimen and the maximum feed rate. The temperature at the point of impact of the laser beam is regulated in a closed feedback loop from a monochromatic pyrometer. The plasticizing temperature can be set in any range, for the tested steel it is in the range (1050 °C-1100 °C). Based on the pyrometer indications, the data sent to the laser device regulates the laser power so that the temperature does not exceed the set values. Depending on the pipe diameter, the laser power automatically varies in the ranges mentioned above. For this purpose, the

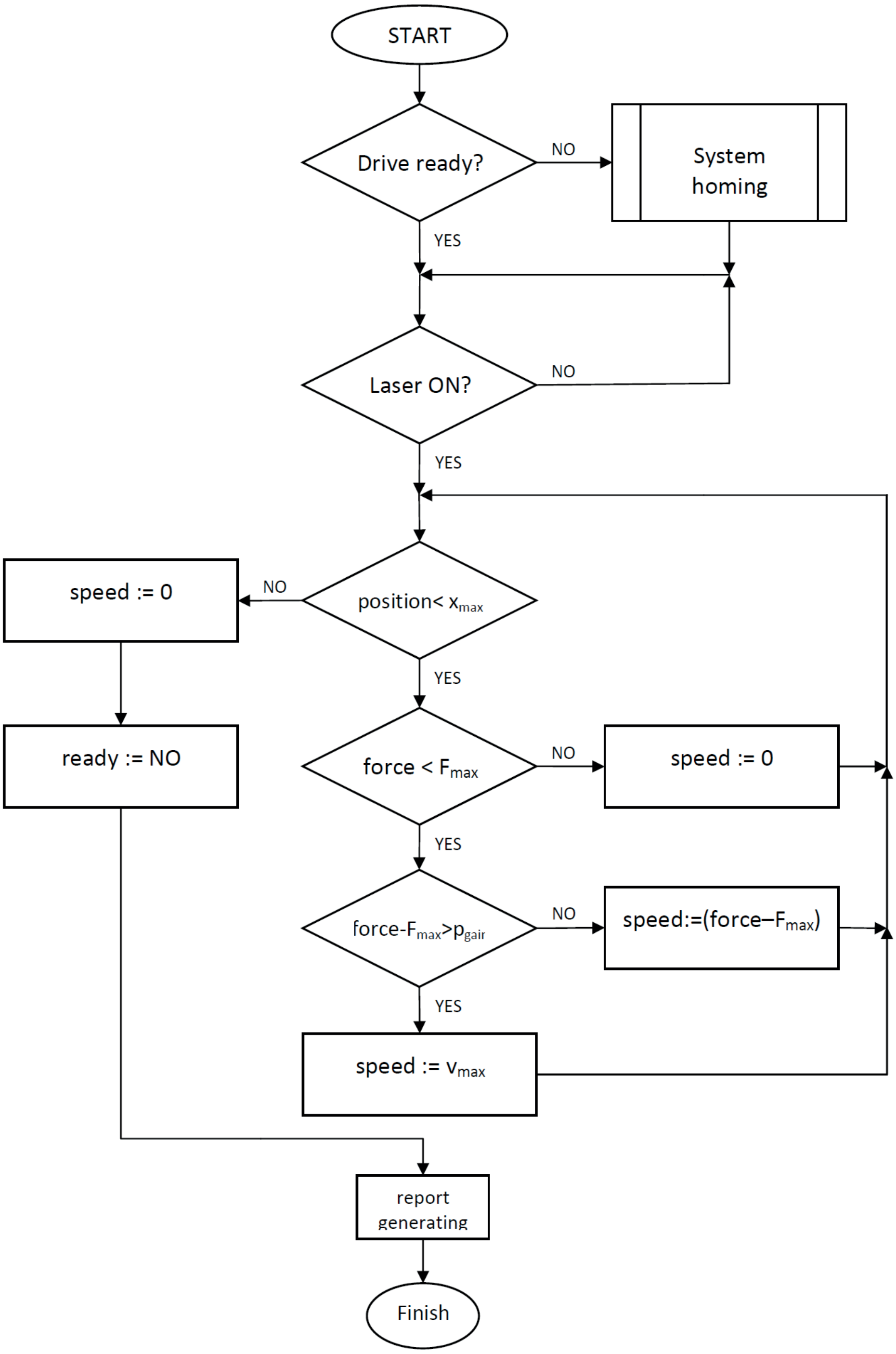


Figure 5 *The block diagram control of the mechanically assisted laser forming process*

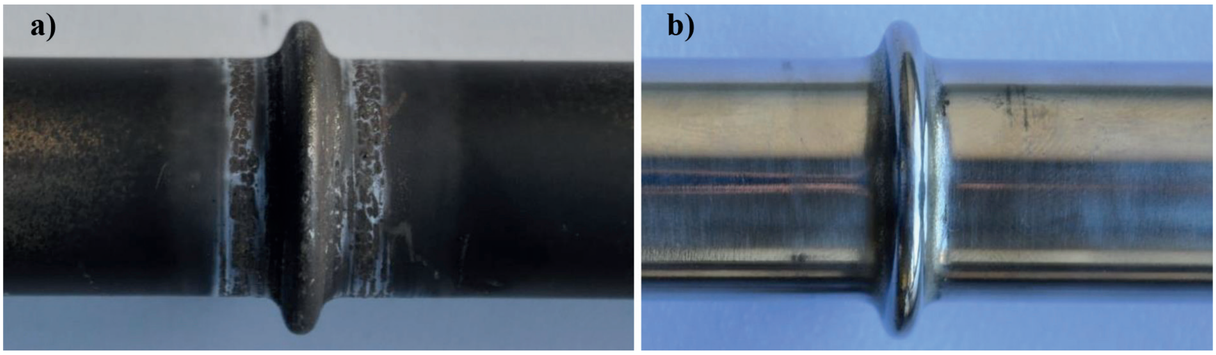


Figure 6 *Example of the final bellow-lens shape: a) just after process with absorber, b) after polishing*

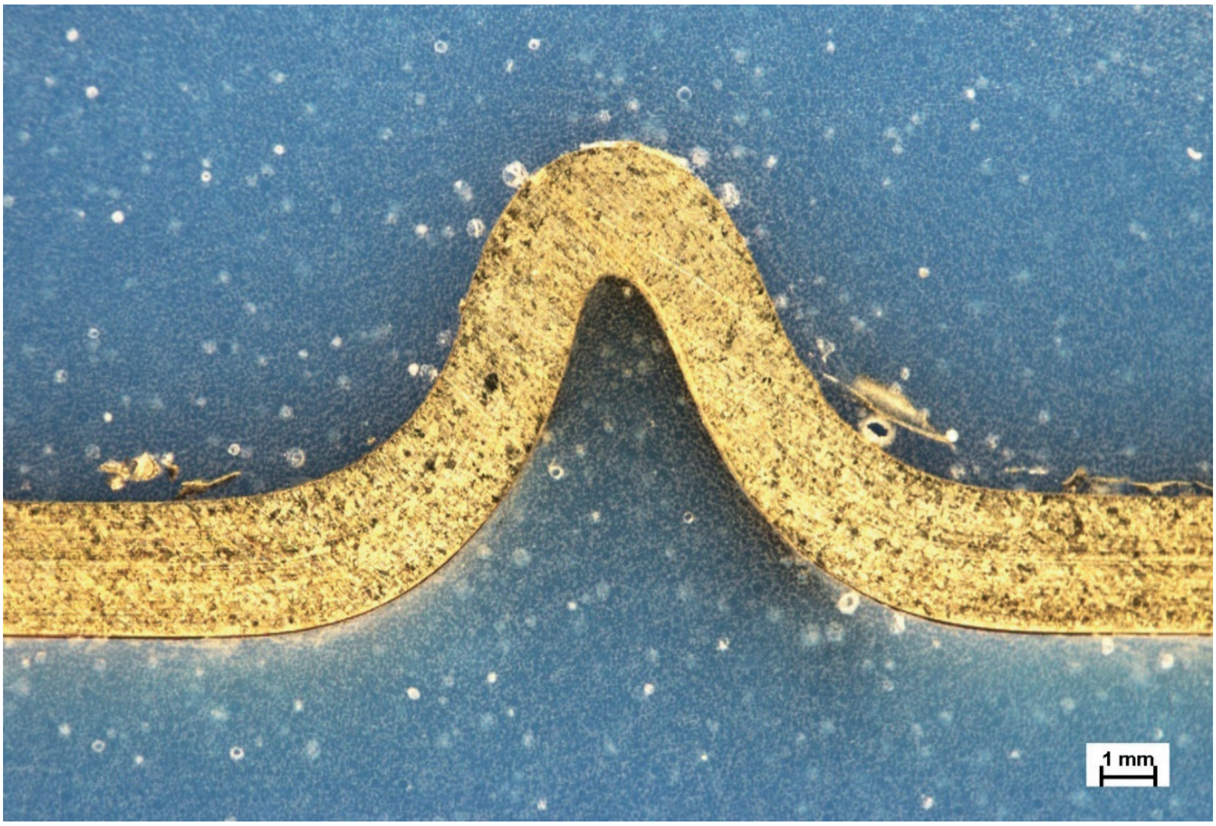
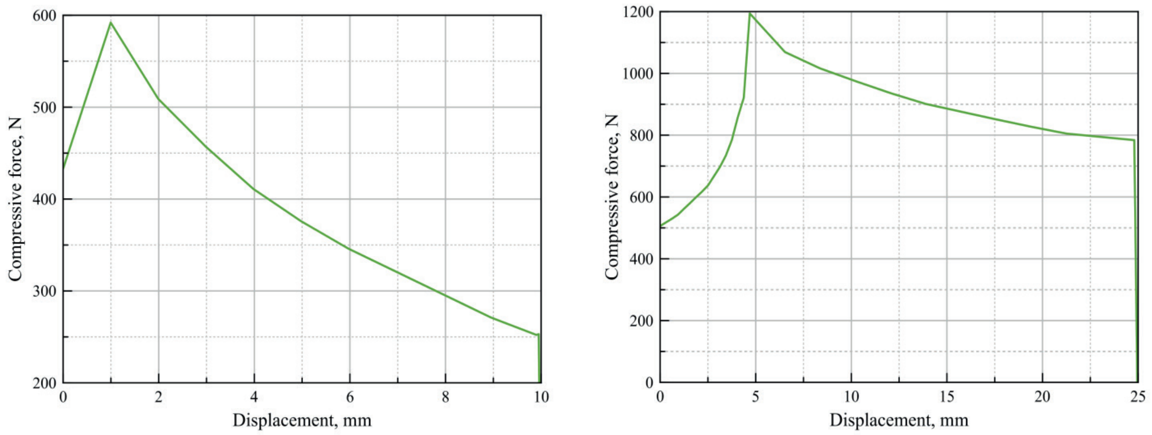


Figure 7 *An exemplary view of the expansion joint bulge formed after the mechanically assisted laser forming process*



a) *b)*

Figure 8 *Change of the pushing force during the element compression under expansion joint manufacturing process: a) for DN20 pipe, b) for DN50 pipe*

PID SENSORTHERM REGULUS RD00 00 regulator, controlling the CO_2 laser power, was used. Pre-processed measurement data are sent to the application on an ongoing basis for their visualization and archiving in the test report. The implemented actuator control algorithm is shown in the block diagram in Figure 5.

The following were used to build the research equipment:

- Siemens S7-1200 6ES7212-1AE40-0XB0 PLC controller,
- linear actuator Thompson PC-40-PA-999-B05-0250-X-F-1,
- SM86/156-4208B stepper motor - 12.2Nm,
- TB6600 stepper motor driver,
- strain gauge force sensor SPAIS FT - 5306L/±5 kN/M12x1.25/DL/5mb,
- amplifier for strain gauge WObit WDT11-U force sensors.
- SENSORTHERM REGULUS RD00 00 temperature controller with a monochromatic pyrometer.
- PC.

After the experiment performed with the parameters given in the previous chapter, it was possible to obtain the shape of the bellows-lens on the pipe. An exemplary view of the finished element is presented in Figure 6.

The cross-section of the finished element was done to check the internal shape of the created expansion joint. The view of the intersection is shown in Figure 7.

During the process, the pushing force F was also registered, the operation of which led to creation of a bellows-lens metal expansion joint. The registered forces data are presented in Figure 8.

4 Conclusions

The conducted experiment proves that the presented concept of metal expansion joints manufacturing, the so-called bellow-lens, is correct. Obtaining elements with the required geometry was preceded by many empirical tests. The selection of correct parameters of mechanically assisted laser forming, such as: the plasticization temperature of the element, the width of the plasticization zone, the compression length and the compression speed, have a significant impact on the final shape of the bellows-lens. The preliminary studies, mentioned in this paragraph, were not cited in this paper, but they can be traced under [13].

The authors confirmed that the developed technology allows the production of correct elements. The authors are convinced that the appropriate equipment will allow the production of a number of bellow-lenses on the one tubular element. It is impossible at the moment, due to the initial period of research and due to technological limitations.

As shown in Figures 6 and 7, the element geometry is correct. The buckling that forms the bellow-lens has no defects in the form of cracks or discontinuities. The upset is symmetrical and has appropriate fillets, which the authors hope, will be able to work under the correct pressure and temperature.

The diagram of force changes as a function of the piston displacement (during pipe upsetting) is also worth noting. In both cases, a characteristic peak (maximum compression force) is observable, which appears at the beginning of the process. For a DN20 pipe element, the maximum compressive force is approx. 600 N, while for a DN50 pipe element, this force is twice as high and amounts to approx. 1200 N. It should be noted that this force only reaches its maximum value for a while and it decreases. Observations during the tests show that this force reaches its maximum value when the bulge in the shape of a bellow-lens begins forming. After the bellow-lens started forming, this force diminishes. Thus, the onset of upset formation is a critical point in the process when it comes to the need to apply an appropriate force.

In the future, the authors plan to more accurately recognize the element's forming process itself by using, among others, measuring instruments with better resolution. The process temperature is approx. 1100° C and this is the hyper-quenching temperature of the X5CrNi18-10 grade steel. Therefore, the authors suspect that the crystal structure of this steel should remain an austenitic structure (without changes to material properties). Therefore, material tests are planned for the finished element, hardness tests and the distribution of alloying elements, after the laser forming process in the area exposed to the laser beam and crushing zone. In addition, strength tests of the finished element are planned. In the future, an FEM analysis of the mechanically assisted laser forming process is also planned. The results of the above-planned work will be published in the future.

Acknowledgement

The research reported herein was supported by a grant from the National Centre for Research and Development. Program title: Lider XI, grant title: “Development of new type metal expansion joints and their manufacturing technology”, contract number: LIDER/44/0164/L-11/19/NCBR/2020.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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